

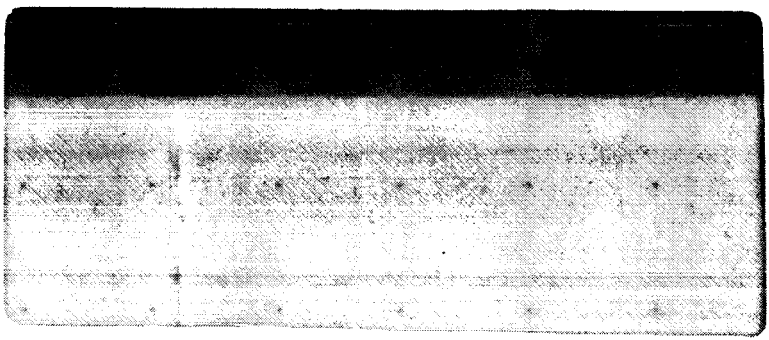
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**YARDNEY ELECTRIC CORPORATION**  
"Pioneers In Compact Power"  
40-52 LEONARD STREET, NEW YORK 13, NEW YORK



*2"*  
*1/2 inch*  
Research & Development Study  
of the Silver-Cadmium Couple for  
Space Application

Report No. 1

(NASA Contract No. NAS 5-3452)

First Quarterly Progress Report

1 July 1963 to 30 September 1963

National Aeronautics and Space Administration

Goddard Space Flight Center

Greenbelt, Maryland

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*see cover*

*George A. Dalin 1963 29 p 2/2*

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#### PURPOSE

The purpose of this program is to study the electrode reactions which take place in the sealed silver oxide-cadmium cell under satellite regimes. The findings are then to be used for developing improvements in design and construction to be incorporated in 30 sealed cells.

ABSTRACT

19592

The program was initiated with a review of published papers and internal reports.

Because extended cycling is a principal means of determining the effect of construction variations and because of the consequent need for special equipment, a complete program for the year, showing all equipment requirements has been drawn up.

Construction of special equipment is under way. Some portions are complete and already in use; completion of the remainder is expected by November 25th.

Special cell design is complete, special dummies have been constructed and are cycling.

Preliminary work on gas recombination has been carried out. A test chamber which will accommodate a reference electrode and thermocouples has been constructed. The top of the chamber is fitted with hermetic seals through which current can be passed, and with connections to gas valves and a pressure gauge.

*Arthur*

## THE RESEARCH PROGRAM

The research program has been divided into four separate phases, each dealing with the distinct objectives set forth in the NASA statement of work. Since the phases are independent of each other, i.e., the experiments in one phase do not require the results from any other, the work on all four objectives can proceed simultaneously.

A summary description of each phase is given below; it is followed by a more detailed description of each.

### Phase 1

This phase, which comprises items #1, 4, 5 and 7 in the NASA statement of work, deals with the study of the characteristics of silver and cadmium plates of various constructions and composition.

### Phase 2

Investigation of rates of gas evolution and the mechanism of recombination with active materials as a function of temperature and various separator systems and plate constructions. Also included in this phase will be the suppression of argentic voltage by trickle charging.

### Phase 3

Investigation of physical and chemical changes occurring at the silver electrode during long constant potential charging.

### Phase 4

Investigation of the positive plate variables which affect the length of the silver monoxide plateau during long and short orbit regimes.

## DETAILS OF PROGRAM

### Phase 1

To study the reactions occurring at the electrodes, plates will be cycled both in dummies and in cells. The plates will also be subjected to analysis by a number of techniques both before and after cycling to determine what changes in structure occur. At this time, the intention is to measure surface area of positives and negatives by double layer capacitance, acceptance of charge by analysis for  $\text{Ag}_2\text{O}$  and  $\text{AgO}$  using a polarographic method, and loss in active material by change in weight. We have had some measurements of surface area on silver powder and on a silver plate made by the BET method. These results will be compared with values from transients and from the Fisher Sub-Sieve Sizer.

A variety of silver plate and cadmium plate constructions are cycling in dummies. The purpose of this type of test is to separate the electrode reaction from extraneous factors such as the effect of specific separators, changes in electrolyte concentration during a cycle, and the ratio of positive active material to negative.

In each dummy, the test electrode occupies a central position between two bare counter-electrodes. For the study of the silver electrode, the counter-electrodes are also of silver; for the cadmium electrode, the counter electrodes are of nickel.

The reference electrode for the silver is a silver plaque charged to the extent of 50% of the monoxide capacity. For the cadmium electrodes, the reference consists of electroformed cadmium powder pressed onto a grid of expanded silver sheet. This type of electrode was used in preference to a pressed oxide because it eliminates the charging step. Although satisfactory readings are obtained, this type of reference will be replaced because it has proved rather fragile.

After assembling the test plate, counter-electrode, and reference electrode, the cell case is filled with electrolyte, the electrode leads are taken out through hollow lead screws in the cell cover, and all openings are waxed shut. The dummy regime includes cycles at a variety of temperatures as shown in Table 1.

At the end of the cycling, the plates will then be examined to determine the extent of the changes in properties from the initial values.

Thirty-eight dummies, in 19 pairs have been constructed. One of each pair is undergoing charge and discharge at rates corresponding to the short orbit and one to the long orbit.

Table 2 shows the combinations of variables which are being tested in dummies. As can be seen, effects of plate density, electrolyte concentration, silver particle size, and type of cadmium are being investigated. The experiment is designed to show the direction in which performance is changed as a result of change in a test variable. Where significant effects become apparent, the test can readily be amplified to explore any variable more intensively. This can be done because the dummy design makes it possible to assemble any test combination easily.

Although recent work (Eagle-Picher Final Report on sealed Cd-AgO June 30, 1962 Contract DA-36-039-SC-85370) has shown that the rate at which the silver plate loses weight by shedding increases as the plate density is decreased, we are still interested in determining the effects of electrolyte concentration and silver particle size since these factors may influence performance directly as well as indirectly through the silver density. The indirect effect can be due to an interaction in the sense that a performance change resulting from a change in silver density and a change in electrolyte concentration can be substantially different from the sum of effects of the individual changes. In addition, a change in particle size, or a change in electrolyte concentration can alter the rate of shedding of silver.

The study of cadmium plates made from a variety of raw materials stems from a rather different phenomenon. The electrochemical utilization of cadmium always proves to be lower than theoretical. At low current densities, 75% seems to be the best utilization. At higher current densities the utilization falls off sharply. The situation is rendered more complex by the fact that conductivity of the oxide is poor, making it necessary to add conductor to the powder.

It has been our experience that plates made from pressed cadmium oxide are quite different in performance from those made from pasted cadmium oxide. Following up this matter we have included in the study plates made from cadmium hydroxide and from cadmium carbonate. In addition we are attempting to determine whether benefits will result from any specific conductive additive.



Cadmium plates must be formed under pressure as Shepherd of NRL has shown. All of the cadmium plates were formed in this way. After forming they were washed and dried and then assembled into cells.

The test regime for the dummies was worked up to correspond, on the one hand, to the specified orbital regimes, and on the other, to the arbitrarily selected plate size. Table 3 shows the calculations leading to the selected current densities and regime.

An analogous procedure was followed in drawing up the construction pattern for testing in cells. The pattern is shown in Table 4. Here the effect of separators and the restricted quantity of electrolyte are added to the electrode reactions.

In each cell the pack consists of two positive electrodes and three negative electrodes. The design is such that the positive electrodes are limiting, i.e., the negative electrodes possess excess capacity. Reference electrodes are built into all cells.

The cells, all of which are sealed, and are fitted with pressure gauges and valves, will be put through the same sequence of evaluation cycles (deep cycles, variety of charge and discharge rates, variety of operating temperatures) as the dummies. They will then be subjected to cycling on the long and short orbital regimes.

In the 100 minute regime, each cell will be discharged to 35% depth of discharge (DD) in 40 minutes and charged in 60 minutes. In the 24 hour regime, the discharge time will be 1 hour to 70% DD and the charge time will be 23 hours. Periodically, the cells will be deep-cycled to determine changes in capacity and ratio of argentic to argentous capacities on discharge.

After a number of cycles to be based on changes in performance, cells will be dissected. Plates will be weighed, the surface areas will be measured, and plates rebuilt into cells, to determine individual positive and negative plate capacities.

## Phase 2

A principal problem in the operation of sealed cells is the prevention of excessively high pressures. Gas can be produced as the result of inefficiency of charge, as is the case with nickel electrodes, or as the result of cell reversal on discharge.

Of course, in the operation of individual cells it is easy to avoid cell reversal. In the deep discharge of batteries, however, where only the battery voltage is monitored, small differences in capacity can result in reversal of individual cells. The same difference between operation of cells and batteries prevails with respect to end of charge. Even an electrode which is essentially 100% efficient while on charge, as is the silver electrode, can produce gas if charge is carried too far.

Where cells are designed to be positive limiting on charge and where the cells are only partially discharged, then even though cycled as a battery, coping with the oxygen produced at the end of charge, or on trickle charge is the only problem.

Naturally, should the negative electrode, in our case cadmium become limiting on charge, as the result, say, of an aging process, then, hydrogen evolved on charge becomes a problem. Moreover, if the cell loses capacity to the point where it cannot provide the required output, or if an unanticipated deep discharge is called for, then cell reversal can occur. Under these conditions, either oxygen or hydrogen can be evolved. Table 5 summarizes the gases evolved as a function of the limiting electrode and the direction of current flow.

Table 6 goes a step further and shows the possible recombination reactions. Only the reaction of oxygen with cadmium is known to proceed at a rate rapid enough to be useful for reducing the pressure. However, the rate of reaction of hydrogen with silver oxide is measurable though slow, and the reaction of oxygen with silver is thermodynamically possible. The listed potentials of hydrogen and cadmium oxide in basic solution are very close so that a reaction on stand is questionable. There is a possibility that the shift in potential of the negative electrode during discharge might be great enough to cause the reaction to proceed. This would be analogous to the effect found by Dehmelt and Von Dohren as reported at the 1959 Signal Corps Power Sources Conference.

For the present, the major emphasis must be on the reaction expected during overcharge of the positive, namely cadmium plus oxygen. A large amount of work has been done on this reaction in connection with the nickel-cadmium cell. In this cell the negative has in all cases been the impregnated nickel plaque.

The situation here becomes somewhat confused because there seems to be fairly general acceptance of the claim that the reaction between  $O_2$  and cadmium is electrochemical rather than chemical. One basis for this claim is the experiment of Dr. Baars in which he showed that wet nickel in contact with oxygen and connected by a wire to a deeply submerged cadmium plate could bring about the electrochemical oxidation of the cadmium and reduction of the oxygen. Moreover, in papers given at the Fall meeting of the Electrochemical Society, it was claimed that the reduction of oxygen in the sealed Ni-Cd cell takes place on the surface of the nickel (of the negative).

However, Dehmelt and Von Dohren showed that while nickel alone would reduce oxygen if made negative, they also showed that the rate was potential - sensitive as well as pressure - sensitive. They found that the rate was faster on a plaque impregnated with cadmium and still faster on pure cadmium plates so long as the plates were made slightly negative with respect to the reversible potential. At positive potentials, the rate was suppressed by formation of thick layers of  $Cd(OH)_2$  of poor electronic conductivity. They stated that at zero potential, the reaction  $Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$  also occurs, so that the oxygen reaction rate cannot be observed.

We made some preliminary studies of the reaction between  $O_2$  and cadmium. The work was oriented toward determining only the relevant variables and consequently is not sufficiently quantitative; however, the cell construction has pertinence and the data are evidently worth analyzing.

In one group of tests the cell pack consisted of a nickel plaque positive, Webril and nylon-dynel felt separator and a negative prepared by pasting 2 micron  $CdO$  with 5% of 8 micron silver powder on a  $30 \times 30 \times .0075$ " copper wire mesh and then charging. The negative was spaced away from the cell case by a piece of expanded silver sheet. The objective was to keep one face of the cadmium plate accessible to the gas phase. Cell pressure was monitored with a manometer. Current could be put through the cell.

The cell pack was weighed, soaked in KOH for 24 hours, blotted free of excess KOH and reweighed. The gain in weight is referred to as maximum fixed electrolyte. The pack was inserted in the test chamber which was then sealed. The free volume of the cell was determined by connecting a flask of known volume at a known pressure of nitrogen, allowing the gas to enter the evacuated cell and noting the final pressure.

To make a determination, the cell was evacuated, oxygen was introduced, and the rate of pressure decrease was followed. A number of interesting observations were made.

1. As would be expected, the rate of recombination decreased sharply as the quantity of KOH was increased by 10% increments beyond the maximum fixed electrolyte quantity.
2. The pressure-rate of recombination relationship was of the form  
$$\log r = a + b \log P.$$
 For 38% KOH the data fall close to  $r = kp$ .
3. 38% KOH gave higher recombination rates than 30% which in turn was higher than 44% KOH.
4. Using the relationship  $1 \text{ mA} \cdot \text{h} = .210 \text{ ml of O}_2$ , the recombination rate at 1 atm. with 38% KOH is equivalent to  $20.7 \text{ mA/in}^2$ . See Figure 1.
5. The passage of current through the cell to generate oxygen on the nickel had no effect on the oxygen recombination rate. This would seem to be in direct conflict with the findings of Dehmelt and Von Dohren. Although the cadmium must have been rendered more negative to cause current to flow, since no reference electrode could be incorporated in the primitive design, we can only estimate that the shift was too small to give a detectable change in recombination rate.

A similar experiment was set up using charged silver oxide plates and hydrogen. Figure 2 shows the calculated maximum permissible overcharge current density as a function of equilibrium pressure based on the results obtained. As can be seen, at room temperature the rate of recombination of hydrogen at 1 atm. pressure is equivalent to  $0.156 \text{ mA/in}^2$ , a very low rate indeed. Figure 3 shows some of the data points and gives an idea of the reproducibility.

A few tests were made in cells. Again, 38% KOH proved superior to higher and lower concentrations for oxygen recombination. The lowest quantity of KOH gave the most rapid recombination, and the introduction of semi-permeable separator (cellophane) lowered the rate.

A new reaction chamber for studying gas evolution and recombination reactions has been constructed. See Figure 4. The top of the chamber is fitted with a number of lead-through seals so that current can be passed and connections can be made for thermocouples and reference electrodes. The top is also fitted with a compound pressure gauge and two gas valves thus making it possible to pass a gas through the cell continuously. The objective here is to measure the effects of various plate compositions

and constructions, wraps and electrolyte concentration and quantities.

This last variable is the most difficult to control in practice since porosities of components vary from specimen to specimen and since reaction rates are so dependent on degree of wetness. The chamber will be used to study methods of establishing wetness on a reproducible basis.

Another major use of the chamber will be to determine reaction rates as a function of plate polarization and state of charge. Also the chamber can be thermostatted to determine the effect of temperature.

To determine the effects of cycling, similar tests are being set up using sealed cells. Table 7 shows the experiment design. The principal variables are positive plate density, negative plate density and construction additives included for catalysis, separator type and construction, electrolyte concentration and quantity.

Tests will be run on both the short orbit and the long orbit. One cell to be constructed in this group will be subjected to trickle overcharging in the attempt to find the mechanism by which the argentic voltage is eliminated on discharge.

At this writing it seems possible that increased resistance results from more nearly complete conversion of silver in the interior of the powder. To investigate this possibility, we intend to dissect cells, wash and dry the plates and examine them for increase in dry resistance. Wet resistance measurements can be erroneously low because of parallel current flow in the electrolyte in the plate pores.

### Phase 3

The effect of constant potential charging on cells will be studied in this phase. As with trickle charging, the effects of long c.p. charging may be due to increase in resistance. To study the effect, we plan to run tests according to Table 8.

Lead will be studied as an additive because it is known to form a semi-conductor on oxidation. The high conductivity of this semi-conductor should show up in constant potential charging as an increase in current over that drawn by the cells with  $P_0$ . The series with grid conductivities varying from that of Exmet 1 to that of solid sheet should show up in the same way.

#### Phase 4

The objectives in operating on the argentous plateau are to avoid gassing at the end of charge, to avoid the change in potential as the plates drop from argentic to argentous oxide, and to decrease the difference between charge and discharge voltages. The silver which is ordinarily used in silver-cadmium cells will accept only about 30% of its total intake on the argentous level. To operate a cell with this type of silver on the argentous level, and still maintain capacity, would require that the silver be increased by a factor of 10/3. Such a change would be undesirable because of the increase in weight and cost.

Two methods have been introduced to counter this difficulty. The first is the use of fine silver which gives a much longer argentous charge, and the second is the use of palladium as an additive.

It seems likely that the very fine silver particles are almost completely converted to  $\text{Ag}_2\text{O}$  before the thickness of the argentous layer exceeds the distance through which an oxygen ion can penetrate at the lower potential. Under these circumstances, as the metallic silver is exhausted the electrical resistance of the plate would suddenly become very high and the voltage of a plate on constant current charge would rise steeply to the gassing potential. The charge curve is consistent with the above mechanism. With an efficiency of about 45% compared to silver operating on both levels, the increase in weight and size, since only the silver need be increased, is not excessive for many applications.

The principal problem is to retain the desirable properties, since previous work indicates that the silver may go into solution and crystallize out in coarser form. The palladized silver also provides only a temporary effect. There are a number of courses available which we shall explore. In the first, we shall investigate the performance of different types of silver to determine for how many cycles the effect persists. The plates will be made up on different grids to determine how the variation in grid contact surface affects the charge curve. The electrolyte will also be varied since the solubility of silver oxide varies with electrolyte concentration. Two different separator systems will be used to explore the effects of this variable. Table 9 shows the combinations which will be studied. The short orbit will be used for the study to save time.

In a second group of cells, the effect of a variety of additives including palladium is covered. See Table 10. The objective of the various carbons is to improve the conductivity of the argentous oxide. It will be significant if improvement of conductivity eliminates the steep potential rise at the end of the argentous change. The same point will be made by varying the charge current density; this should disclose whether the potential change consists only of IR drop.

#### PROGRAM FOR THE NEXT PERIOD

##### Phase 1

Complete scheduled cycling of dummies over a temperature range on long and short orbits. Examine plates to determine weight loss and change in surface area. Form cells for study of electrode processes, and then cycle.

##### Phase 2

Start recombination studies in special pressure vessels and in cells. Compare recombination rates on cadmium and on cadmium impregnated negatives. Start trickle charging of cells.

##### Phase 3

Start cycling with charging at constant potential. Also start continuous charge at constant potential to determine pressure changes. Plates will be examined periodically for weight and surface area changes.

##### Phase 4

Complete cells for argentous voltage operation. Start on short orbit regime.

Time consumed for the period of July 1, 1963 up to September 30, 1963 on this assignment were 650.5 engineering hours and 265 technical hours.

## A D D E N D U M

### STATEMENT OF WORK

#### General

Using contractor furnished labor and materials, the contractor shall conduct a research study of the silver cadmium couple for space applications. While the Contractor shall expend some effort on electrode improvement and incorporation of the improvements in sample sealed cells for proof of design tests, the Contractor's major effort shall be applied to understanding the reactions of the silver oxide ( $\text{AgO-Ag}_2\text{O}$ ) and the cadmium electrodes.

#### Details

The Contractor's study shall be designed to achieve the following objectives:

- (1) An understanding of the reactions occurring at the silver ( $\text{AgO-Ag}_2\text{O}$ ) and cadmium electrodes during cycling and the effects of temperature ( $-15^\circ\text{C}$  to  $+50^\circ\text{C}$ ) on these reactions.
- (2) Determine the rates of gas evolution and the mechanism of gas recombination, also as a function of temperature ( $-15^\circ\text{C}$  to  $+50^\circ\text{C}$ ). Some data on pressure variation in a silver cadmium cell are shown in Figure (1). Analysis of gas compositions will be made and the effects of electrolyte level on gas recombination will be studied.
- (3) An understanding of the physical and/or chemical changes occurring at the silver electrode during long constant potential charging. Some data on the depression of the silver peroxide portion of the discharge curve is shown in Figure (2). This change in cell characteristics can be brought about by a constant potential charge for several weeks or cycling with long trickle charge periods.
- (4) Improvements in the porosity and methods of construction of cathode and anode.
- (5) Improvement in the efficiency of the negative plate. Efficiency here is construed to mean the ratio of the actual ampere hours output of the electrode to the theoretical ampere hour output of the equivalents of active material in the electrode.
- (6) Determine the feasibility of design of cells which will operate on the silver monoxide plateau only during long (24-hour) and short (100 minutes) orbits. During this phase of the work, the possibility of cycling the silver cadmium system at a voltage efficiency greater than 85% while maintaining maximum usage of the active material shall be investigated.



Statement of Work (continued)

- (7) An investigation if any change in properties of conventional separators affects the characteristics of the silver cadmium couple. This study, however, shall not include any extensive work on cell seals or separators. Test cells shall be fabricated in plastic cases and sealed in epoxy. Separators required for electrode studies shall be of the type commonly used in silver zinc or silver cadmium systems.

Table I

Test Procedure for Phase 1

Group 1	Group 2
38 Dummies	48 Cells

Deep cycle to establish capacity

Short Orbit	Long Orbit	Short Orbit	Long Orbit
-15°C	-15°C	-15°C	-15°C
+25°C	+25°C	+25°C	+25°C
+50°C	+50°C	+50°C	+50°C

Continue cycling at room  
temperature until failure.

Dissect dummies and cells.

Determine loss of weight from plates.

Determine change in surface area.

Short orbit; 35 minutes discharge, 65 minutes charge.

Long orbit; 1 hour discharge, 23 hours charge.

TABLE II PHASE I, GROUP I

A) POSITIVE ELECTRODE DUMMY TEST

	E 1	E 2	E 3
D 1	C 1		
	C 2		
	C 3		
D 2	C 1		
	C 2		
	C 3		
D 3	C 1		
	C 2		
	C 3		

CODE

C1 = 31.0% KOH SOLUTION  
C2 = 36.5% " "  
C3 = 42.0% " "  
D1 = ACTIVE Ag 3.6g/cc  
D2 = " " 4.2 "  
D3 = " " 4.8 "  
D4 = ACTIVE Cd 2.3g/cc  
D5 = " " 2.8 "  
D6 = " " 3.3 "  
E1 = HAHS Ag POWDER GRID 5Ag15-1  
EXMET

E2 = HC " " "  
E3 = FR " " "  
E4 = PRESSED CdO " "  
E5 = PASTED CdO " 3Ag5-2/O  
E6 = PRESSED Cd(OH)<sub>2</sub> " 5Ag15-1  
E7 = " " " 3Ag 5-2/O  
E8 = " CdCO<sub>3</sub> " "  
E9 = Cd IMPREGNATED Ni PLAQUE  
E10 = PASTED CdO GRID: 5Ag15-1  
E11 = PRESSED CdO + 2% SHAWINIGAN  
BLACK GRID: 5Ag15-1  
E12 = PRESSED CdO + 2% GRAPHITE  
GRID: 5Ag15-1  
E13 = PRESSED CdO + 5% Ag (FR)  
GRID: 5Ag15-1

NOTES:

- 1) TWO CELLS OF EACH TYPE (ONE LONG ORBIT & ONE SHORT ORBIT)
- 2) PLATE DIMENSIONS = 2 1/16" x 1 1/4"  
AREA = 2.58 in<sup>2</sup>
- 3) WT. OF ACTIVE Ag / PLATE: 3.93 ± 0.04g  
WT. OF ACTIVE Cd / PLATE: 4.72 ± 0.05g
- 4) AVERAGE PARTICLE SIZES AS OBTAINED ON FISHER SUB-SIEVE SIZER
  - a) HAHS Ag POWDER: 9.0 μ
  - b) HC " " : 7.7 μ
  - c) FR " " : 2.2 μ

B) NEGATIVE ELECTRODE DUMMY TEST

	E 4	E 5	E 6	E 7	E 8	E 9	E 10	E 11	E 12	E 13
D 4	C 1									
	C 2									
	C 3	✓								
D 5	C 1									
	C 2									
	C 3									
D 6	C 1									
	C 2									
	C 3	✓								

TABLE III

CALCULATION OF TEST REGIME

Item No.	Description	Short Orbit	Long Orbit	Unit
Constants (Supplied)				
1	Charge Period	1	23	Hour
2	Discharge Period	0.67	1	Hour
3	Depths of Discharge	35	70	%
Constants (Chosen)				
		Dummy Cell	Dummy Cell	
4	Electrode Dimensions (area)	2.58	7.32	sq. inch
5	Positive Electrode Thickness at 4.8 g/cc	0.020	0.020	inch
6	No. of Positive Electrodes/Cell	1	3	pieces
7	No. of Negative Electrodes/Cell	1	4	pieces
Derived Values				
8	Grams of Silver Powder/Cell	3.93	11.13	grams
9	Ag Capacity at 4.0 gm/Amp-Hr.	0.98	2.78	Amp-Hrs.
10	35% of Ag Capacity	0.343	0.975	"
11	70% of Ag Capacity	-	-	"
12	Total Charge Current	0.343	0.975	Amp.
13	Current Density at Charge	66.5	99.0	mA/sq. inch
14	Total Discharge Current	0.510	1.450	Amp.
15	Current Density at Discharge	5.8	13.3	mA/sq. inch

**FILE**

		E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
		E1E2E3E4E5E6E7E8E9E10E11E12E13									
	D1	C1	C2	C3							
	D2	C1	C2	C3							
	D3	C1	C2	C3							
	D4	C1	C2	C3							
	D5	C1	C2	C3							
	D6	C1	C2	C3							
	D1	C1	C2	C3							
	D2	C1	C2	C3							
	D3	C1	C2	C3							
	D4	C1	C2	C3							
	D5	C1	C2	C3							
	D6	C1	C2	C3							
	D1	C1	C2	C3							
	D2	C1	C2	C3							
	D3	C1	C2	C3							
	D4	C1	C2	C3							
	D5	C1	C2	C3							
	D6	C1	C2	C3							
	D1	C1	C2	C3							
	D2	C1	C2	C3							
	D3	C1	C2	C3							
	D4	C1	C2	C3							
	D5	C1	C2	C3							
	D6	C1	C2	C3							

Notes: 1) Each mark represents one pair of cells.

2) ALL 5 of normal wrap construction, except for one pair which is reverse wrap (as designated).

TABLE V

Limiting Electrode	Gas Evolution	
	Positive	Negative
Charge	Oxygen	Hydrogen
Discharge	Hydrogen	Oxygen

TABLE VI

Limiting Electrode	Gas Recombination Reaction	
	Positive	Negative
Charge	$O_2 + Cd$	$H_2 + AgO$
Discharge	$H_2 + CdO$	$O_2 + Ag$

TABLE VII

## PHASE II

		P1			P2		
		S1	S2	S3	S1	S2	S3
N1	Q1						
	C1 Q2						
	Q3						
	Q1					a c	
	C2 Q2					d	
	Q3					a c	
	Q1					d	
	C3 Q2						
N2	Q3						
	Q1						
	C1 Q2						
	Q3						
	Q1		a b	a			a
	C2 Q2						
	Q3		a b	a			a d
	Q1		a				
N3	C3 Q2						
	Q3						
	Q1						
	C2 Q2						
	Q3						
	Q1						
	C3 Q2						
	Q3						
N4	Q1						
	C1 Q2						
	Q3						
	Q1		a				
	C2 Q2						
	Q3		a				
	Q1						
	C3 Q2						
	Q3						

## Code:

P1 - Positive Plate Density = 4.88/cc

P2 - Positive Plate Density = 3.6 g/cc

S1 - 2 VN 2.5/6 C19

S2 - 2 VN 2.5/3 PVA (1.5)

S - Pellom/3 PVA (1.5)

N1 - Negative Plate Density = 2.3 g/cc  
5% Ni Add.N2 - Negative Plate Density = 2.8 g/cc  
5% Ni Add.N3 - Negative Plate Density = 3.3 g/cc  
5% Ni Add.

N4 - Negative Plate Density = 2.8 g/cc

1) 5% FR Ag Add.

2) 10% FR Ag Add.

3) 15% FR Ag Add.

4) 20% FR Ag Add.

TABLE VII continued

Code:

N5 - Impregnated Nickel Plaque

N6 - Impregnated Silver Plaque

C1 - 31% KOH

C2 - 36.5% KOH

C3 - 42% KOH

Q1 - Normal amount of KOH

Q2 - 1/2 Diff. between normal amount and no free KOH

Q3 - No free KOH

			P1			P2		
			S1	S2	S3	S1	S2	S3
N5	C1	Q1						
		Q2						
		Q3						
	C2	Q1		a				
		Q2						
		Q3		a				
	C3	Q1						
		Q2						
		Q3						
	C1	Q1						
		Q2						
		Q3						
N6	C1	Q1						
		Q2						
		Q3						
	C2	Q1		a				
		Q2						
		Q3		a				
	C3	Q1						
		Q2						
		Q3						
	C1	Q1						
		Q2						
		Q3						

Notes:

Entry "a" Designates 1 N.W. cell on short orbital regime to be followed by long orbital regime.

"b" One N.W. cell on trickle charge.

"c" One R.W. cell on short orbital regime to be followed by long.

"d" One N.W. cell on state of charge vs. recombination effects.

"e" VN = wettable Nylon



# PHASE III - TABLE VIII

## CODE

	P <sub>1</sub>	P <sub>2</sub>	P <sub>3</sub>	P <sub>4</sub>
G <sub>1</sub>				
G <sub>2</sub>				
G <sub>3</sub>				

G<sub>1</sub> - Exmet #5 Ag 15-1  
 G<sub>2</sub> - " " " 8-14/0  
 G<sub>3</sub> - Hot Forged Ag Sheet - .002"  
 P<sub>1</sub> - Std. HC Powder  
 P<sub>2</sub> - HC Powder + 1% Pb (Formate)  
 P<sub>3</sub> - " " " (Plated)  
 P<sub>4</sub> - " " " (Alloy)

## NOTES

(1) P<sub>3</sub> and P<sub>4</sub> will be tried if P<sub>2</sub> shows good results.

TABLE IX

PHASE IV, GROUP I

SILVER POWDER	SEPARATOR	2 NYLON/6C - 19/			2 NYLON / 3 PVA 2.0/		
	C <sub>KOH</sub>	31.0%	36.5%	42.0%	31.0%	36.5%	42.0%
HAHS	5Ag 15-1						
	3Ag 5-2/0						
	5Ag 8-4/0						
HC	5Ag 15-1						
	3Ag 5-2/0						
	5Ag 8-4/0			✓			✓
HC NO PRESINTER	5Ag 15-1			✓			
	3Ag 5-2/0						
	5Ag 8-4/0			✓			✓
FR NO PRESINTER	5Ag 15-1		✓	✓		✓	✓
	3Ag 5-2/0						
	5Ag 8-4/0		✓	✓		✓	✓
MR NO PRESINTER	5Ag 15-1						
	3Ag 5-2/0						
	5Ag 8-4/0						

NOTES: TOTAL NUMBER OF CELLS = 14

PHASE IV GROUP I <sup>TAB 25</sup>  
POSITIVE ELECTRODE ADDITIVES

ADDITIVE	SHAWINIGAN BLACK			DIXON GRAPHITE			CARBONYL NICKEL		LEAD FORMATE		LEAD ALLOY		PALLADIUM		Ag NO <sub>3</sub>
	5%	10%	20%	5%	10%	20%	5%	10%	1%	5%	1% PLATED GRID	5% PLATED GRID	1% REDUCED	1% PLATED	
POS. TYPE %															IMPRG. NI PLATED
H C	SINT.														
	UNSINT.						✓		✓		✓				
F R	SINT.								✓		✓				
	UNSINT.														
M K	SINT.														
	UNSINT.														
IMPRG. N.I.	SINT.														
	UNSINT.														
H A H C	SINT.														
	UNSINT.														

NOTES: 1) TOTAL NO. OF CELLS = 25

# CURRENT DENSITY VS. EQUILIBRIUM PRESSURE AT MAXIMUM FIXED ELECTROLYTE

CADMIUM PLATE  $1\frac{7}{8} \times 2\frac{1}{16} \times 0.028$   
AS Cd = 2.5 G / cm<sup>3</sup>, WEIGHT = 7.8 G.  
Cd PLATE OF CdO (2 μ PARTICLE SIZE)  
PASTED ON Cu MESH 30x30 x .0075 WIRE  
5% Ag POWDER (STANDARD PROD.)

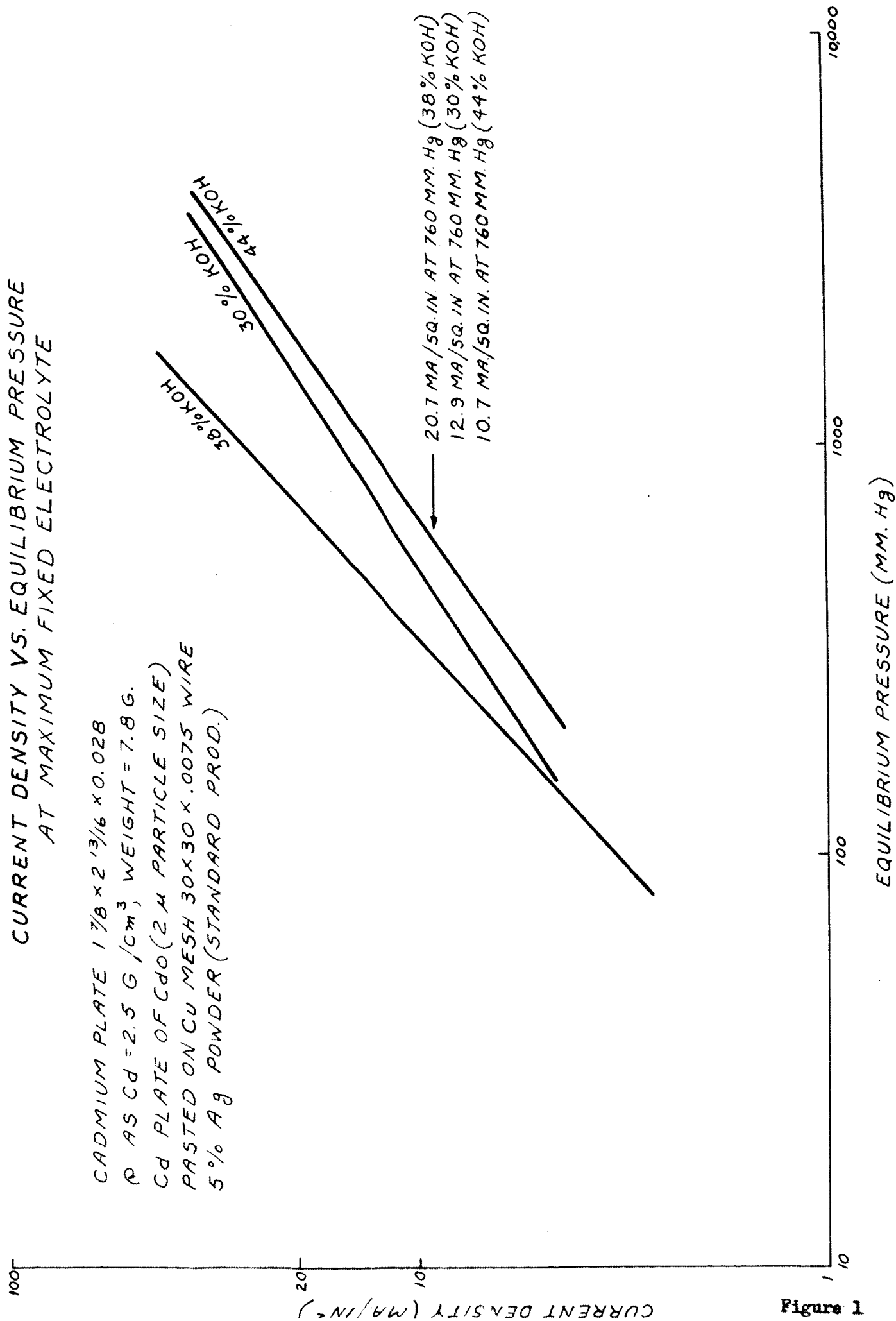


Figure 1

MAXIMUM ALLOWABLE CURRENT DENSITY VS. EQUILIBRIUM PRESSURE  
SEALED CELL -  $H_2 + Ag_2O$

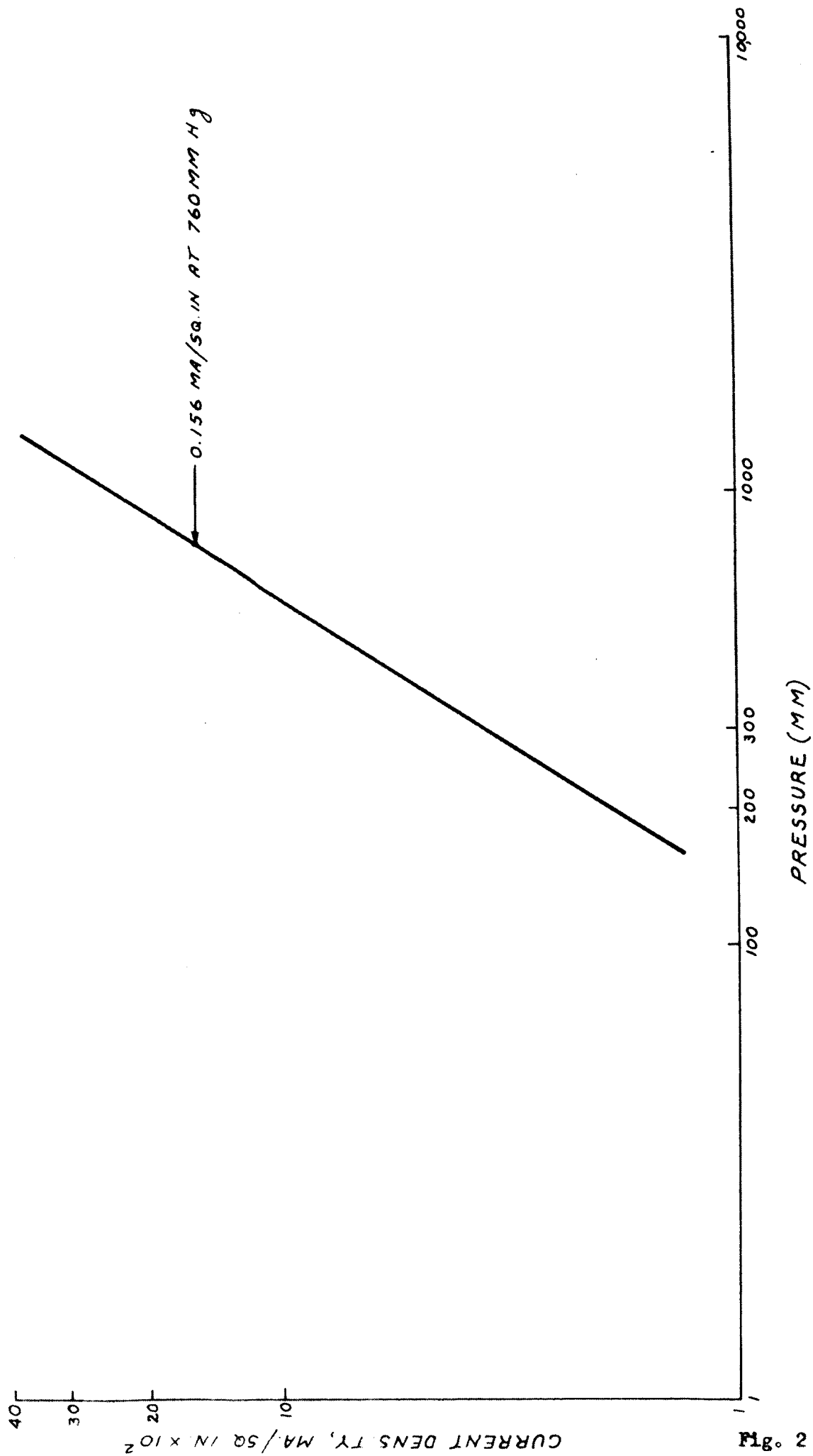


Fig. 2

$dpV/dT$  VS.  $P$ -SEALED CELL -  $AgO + H_2$

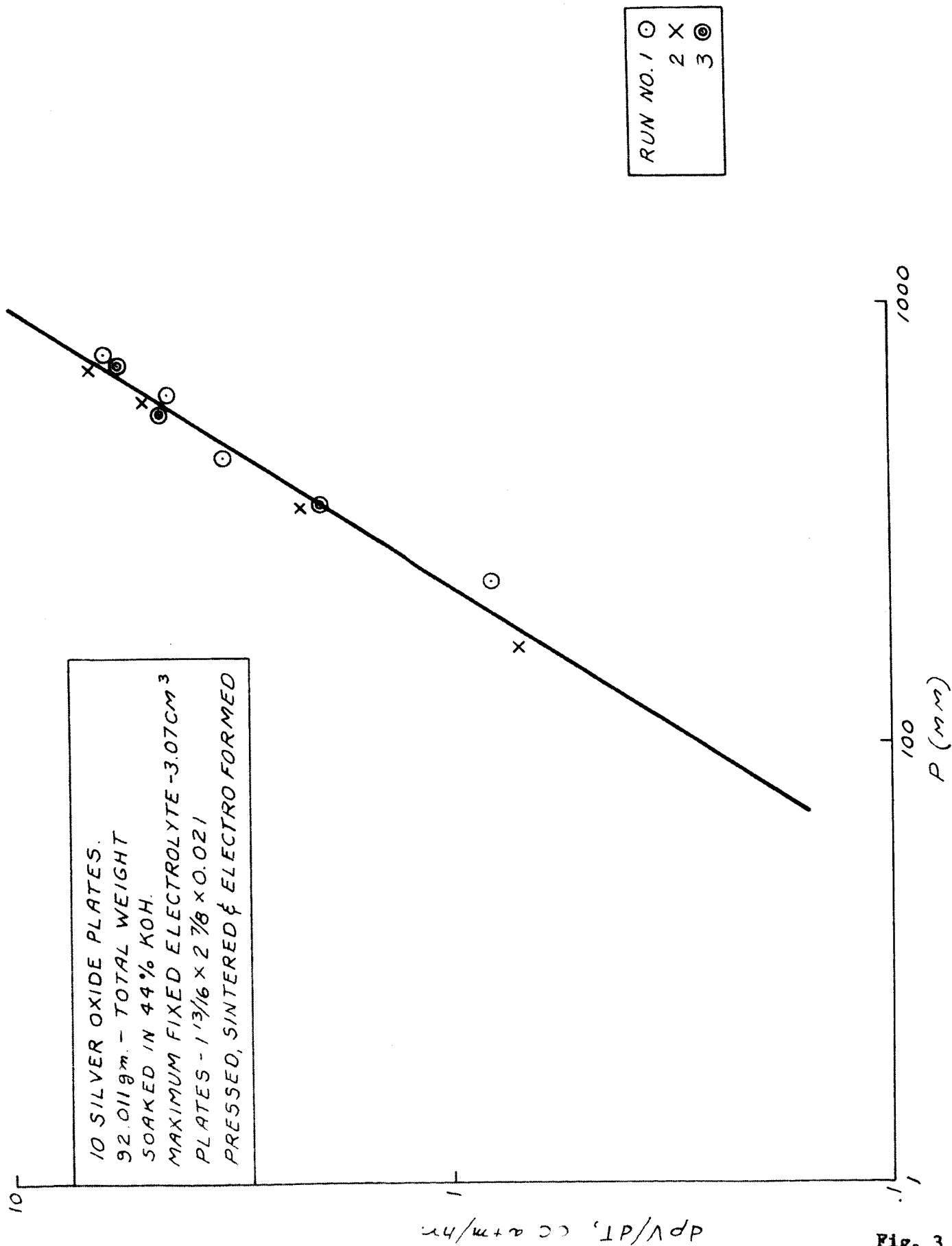


Fig. 3